GuardianAngel: An RFID-based Indoor Guidance and Monitoring System

Nova Ahmed
College of Computing
Georgia Institute of Technology
Atlanta, Georgia 30332–0250
Email: nova@cc.gatech.edu

Stewart Butler
College of Computing
Georgia Institute of Technology
Atlanta, Georgia 30332–0250
Email: sbutler@gatech.edu

Umakishore Ramachandran
College of Computing
Georgia Institute of Technology
Atlanta, Georgia 30332–0250
Email: rama@cc.gatech.edu

***Abstract*—The current ubiquitous presence of RFID technology opens up possibilities for new applications. The RFID enabled indoor pervasive environment is the area of interest for our study. We explore the system requirements for an RFID enabled pervasive system and develop a middleware called *GuardianAngel* to support a monitoring and guidance system for use in an assisted living environment. This paper describes a prototype of such a system, using real RFID devices in a proof-of-concept to evaluate feasibility and emulated RFID devices to evaluate scalability. Our study illustrates the feasibility of such a system, demonstrating greater than 99% accuracy in situ with a confined testbed, and with above 93% accuracy estimated when emulated in a larger environment.**

***Keywords*-Item guidance and monitoring, unobtrusive system**

I. Introduction

It is interesting to note the limited incorporation of pervasive technology in our daily lives. For example, consider the following hypothetical scenarios in an assisted living center for elderly residents: Grandma Ayesha is not able to locate her medicine box with her impaired vision. She requires assistance as she moves along the center. On the other hand, uncle Joe, a quiet person who spends a large amount of time isolated in his room, falls and is injured in the bathroom, but due to his solitary nature his caretakers do not notice his situation.

These hypothetical scenarios are meant to draw attention to situations where non-intrusive monitoring and guidance can enhance the quality of life as well as ensure the well-being of residents in such environments. The problem is challenging since neither Grandma Ayesha nor Uncle Joe would feel comfortable with an intrusive monitoring system (such as video cameras or wearing an ID badge) that would reveal the details of their daily lives to all and sundry. We define this problem in the pervasive environment as a *monitoring and guidance requirement*, where individuals seek guidance information in a complex indoor environment at a desired level chosen by them without compromising privacy. The monitoring and guidance facility introduces challenges in the requirements. A robust guidance system requires positioning information, which enhances the monitoring capabilities. However, monitoring individuals at fine grain level is not desirable for reasons already mentioned. nswers to these questions in this paper.

The GPS based guidance systems do not cover the indoor scenario. The low cost of sensor devices such as passive RFID technology opens up many new possibilities. RFID readers use radio waves to communicate with electronic tags. There has been previous research investigating indoor positioning systems, including the Active Badge location system [1], Radar [2], Cricket [3], LotTrack [4], and Landmarc [5]. The goals of these systems are to figure out the precise location information. There are two major differences of our work related to these existing systems. First, we do not present a positioning system to identify the exact position of a mobile person; rather, we want to give them a sense about where they are in a more coarse grain level at low cost. Second, we differ due to the fact that we do not expect the user to wear a sensor badge or tag. Instead, we assume the user to possess a mobile sensor device that they can carry around that allows them to be in control of when they want the environment to know about their whereabouts. The environment itself is equipped with low cost passive RFID tags. For those cases in which information sharing is desired, security can be improved by the use of available protocols for two-way authentication [6] that can be plugged into our systembut are outside of the purview of this document.Context aware frameworks [7], [8], [9], [10] would serve to enhance the robustness of the solution proposed in this paper. Details of other related works can be found in Section V.

We have developed a two layer middleware solution named *GuardianAngel* that provides system support in such a pervasive environment. The lower layer, named as the *Guidance Layer*, provides the locality information to the user to make guidance decisions. The upper layer, known as the *Monitoring Layer*, has the global knowledge of the environment. The environment is equipped with low cost RFID tags. The guidance layer is supported by a hand held device that has an RFID reader attached to it. The guidance layer is thus able to provide information regarding the resident's current location and immediate objects by sensing the environment. The monitoring layer has the information about the entire environment. The guidance layer under user

control periodically updates coarse grain information defined as the *virtual location* about the resident to the monitoring layer. The guidance layer with its limited capability only keeps partial map information that is acquired on demand from the monitoring layer. If we go back to our previous example: Grandma Ayesha can use her hand held device through the guidance layer to figure out where she is and where her medicine is. Uncle Joe is periodically sending information about his coarse grain location information to the monitoring layer. It detects an unusual amount of time spent in the restroom and sends out an alert signal to the application layer.

The novelty of our approach lies in its uniqueness along three dimensions: first, by virtualizing the user position information; second, by providing a more natural way of gathering environmental information using RFID tags in an unobtrusive manner under user control; and third, by enabling the deployment of large scale indoor environment using low cost passive RFID tags and mobile readers. The rest of this paper is a deeper analysis of the concepts presented above: section II of this paper describes the application scenario and requirements, section III describes the GuardianAngel architecture, section IV illustrates the prototype application, section V describes related works, and section VI presents the conclusions to our research.

II. System Architecture

The physical environment is the indoor space of consideration. The physical environment has RFID tags installed and has the residents carrying mobile RFID readers [1]. The middleware is a data flow oriented system which is responsible for processing the environmental information, monitor the mobile residents and guide the residents as required taking care of all the low level communication and computational details. The residents of the environment (e.g., grandma in assitive living center) and the external user (family members of grandma) get different views of the envornment and can use the user interface to generate dynamic queries in real time.

The GuardianAngel system has several components such as the *Pervasive Environment (PE)*,the *Guidance Server (GS)* and the *Monitoring Server (MS)* composed of virtual stations.The system architecture is presented in Figure 1.

A. Pervasive Environment

The pervasive environment (PE) represents the entire indoor environment under consideration. The PE is logically divided among different regions. The logical definition can be matched with physical entities (e.g., each room of a house or each floor in a building). The zones can be matched to

[1]We assume that it is quite natural for a mobile user to carry a handheld device that incorporates such RFID reader capability. Nokia has developed a cellphone equipped with a passive RFID reader, and there are several mobile RFID readers available in the market today [11]

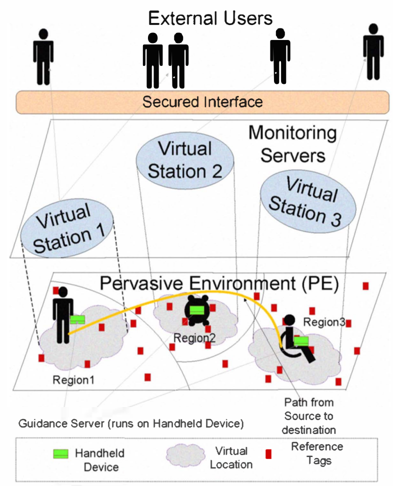

Figure 1. GuardianAngel Architecture.

physical spaces based on application requirements (e.g., a family space region can be subdivided into TV zone, sitting zone and empty zone).

The PE consists of a set of regions $R = \{r_1, r_2, ..., r_n\}$. Each region r_i is equipped with set of reference tags $T_{(r)} = \{t_{(1,r,T)}, t_{(2,r,T)}, ..., t_{(m,r,T)}\}$. The reference tags are logically divided among three different layers for different operations. The *location tags* $T_{(l)} \subset T_{(r)}$ are used to define the current location of an object. The *direction tags* $T_{(d)} \subset T_{(r)}$ are used to define direction information. The *object tags* $T_{(o)} \subset T_{(r)}$ are the tags containing objects of interest. We must note that $T_{(r)} = T_{(l)} + T_{(d)} + T_{(o)}$. The PE requires a *setup phase* by which the environment is installed with RFID tags followed by a *location phase* to use sampling based current location determination.

The setup phase requires two consecutive steps: the *installation of tags* followed by *zone definition*. We use semi-dynamic setup relies on the user to define *root nodes*, which act as anchors for each zone followed bya heuristic algorithm to assign proximate nodes to the same zone. In the *location phase*, the RFID reader equipped with the guidance server uses the environmental information to determine the location information. We use an application defined probability threshold $Pr(location) \geq Pr(Th)$ to place the MO within a *boundary location*, or the location of the MO within a predefined area of the PE. From this, the GS can compute the MO's *virtual location*, which combines historical and present position information to calculate with higher accuracy the current location of the MO. The reading accuracy is determined by a reader's ability to correctly read items compared to the total number of actual items: $Pr(r) = \frac{R}{T}$ where R refers to the number of items correctly read and T refers to the total number of items. The observation accuracy is defined as: $Pr(O) \equiv 1 - (1 - Pr(r))^s$, where s is the

number of samples and O is the probability over a number of samples.

B. Virtual Server (VS)

The VS provides services to the MO present in the designated region for that VS. The major responsibilities include communication management, information management, and status management.

The VS provides three major communication abstractions for effective communication among the system components using a *message board* interface, *path based communication mechanism* and *on demand MO to VS communication*.The *message board interface* provides an open interface for communication among the MOs. There is a single message board in each region. The VS creates a *logical path* among the VSs if guidance information is required for a particular source to destination route. The path creation request is initiated by a request from a particular MO to a VS. A VS contacts its peer VSs and generates a list of VSs that correspond to the shortest path. The cost associated with a path may be expressed using traditional metrics (such as time and distance), or may be expressed based on convenience (e. g., a path without any stairs is lower in cost and more desirable) commensurate with application requirements. The VSs agree on a path creation after assessing the current and predicted future workload in a similar way that is done in RF^2ID [12]. As the MO progresses through the regions, the MO to VS assignment changes based on the current MO location. The VSs transparently transfer status information regarding the MO along the logical path for monitoring purposes. The handoff of VS to MO takes place after the MO changes its region and which is initiated by the VS. The *VS to MO messaging* takes place in a sporadic fashion based on needs. The *information management* of a VS requires managing the physical map and logical map based on application requirements, providing region information to the MO, updating region and zone information and guidance services. The VS provides *guidance information* given the source and destination inputs from the MO. The VS keeps the *status information* of each individual MO in the form of a deterministic finite automata. The status information of the MO is represented as a sequence of states and important information concerning each state. The state change parameters are application dependent and can be adjusted based on requirements. The application can also specify logical rules to be checked dynamically on the MO status. The application should also be able to determine a threshold on how much status information should be stored so that the VS can perform automatic *garbage collection* on MO status information.

C. Mobile Object (MO)

The mobile object (MO) is the mobile entity that contains an RFID reader along with a portable computation and communication device. The residents of the pervasive environment carry the MO. The MO provides the guidance service to the user.

D. Other Components

The system consists of the external users who are interested in obtaining the monitoring information about the residents (MO).

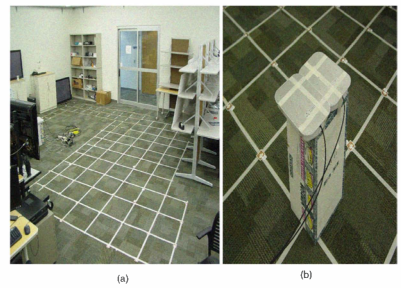

Figure 2. Experimental Setup of the (a) Pervasive Environment. (b) The antenna setup that mimics the reading performance of a mobile user.

III. System Prototype

To study the feasibility of a passive RFID-based location system constructed on the GuardianAngel framework, we have developed a prototype application centered around evaluating various aspects of the system. The evaluation takes place in two phases - we consider the feasibility of an RFID enabled pervasive environment and we consider a large scale building scenario using emulated reader.

A. RFID Testbed

The objective of the RFID testbed using real RFID readers and tags is to determine the feasibility of an RFID enabled pervasive environment. The small scale prototype testbed consists of Alien ALR 9800 model passive RFID reader and Alien Gen 2 passive RFID tags. The prototype is developed using Python, interfacing with the RFID reader using the Telnet protocol. We have placed passive RFID tags in the laboratory setup as shown in Figure 2. The area is covered by (14 x 11) tags and each tag is placed 50 cm apart from each other as shown in Figure 2-(a). We have used a *grid structured* based setup phase to create the PE.

Figure 3-(a) indicates how the sample size varies over time when the mobile object is in motion which shows a large variation in the sample size over time with the average read being 3.33 over 300 samples. Figure 3-(b) shows the neighbor tags with respect to a tag of interest which assures that the majority of the tags read in the sample are mostly the close neighbors. Figure 3-(c) illustrates the consistency of different types of tag reads over time - it is observed that the neighbor tags are not read as consistently as the actual tag reads (which is good news).

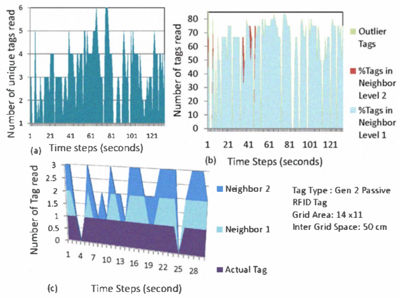

Figure 3. (a) Number of unique tag reads. (b) Number of tag neighbor and outlier tag reads. (c) Number of actual and neighbor tag reads.

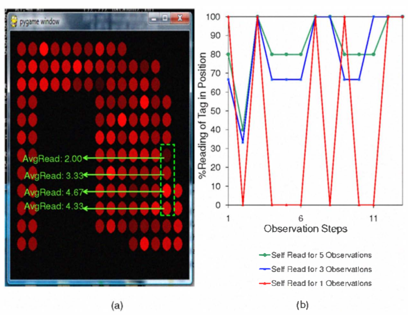

Figure 4. (a) Reading performance for individual tag read. (b) Reading performance with varying sample size.

We have used a buffer size of 5 samples to determine location information. The sample size less than 5 shows larger variations and larger samples require larger sampling time as can be seen in Figure 4-(b). The sample size of 5 proved to be optimal in terms of time and performance. Figure 4-(a) shows the variation of number of readings of individual tags over three samples where each position is visited manually. The tag placement is shown in colored circles where the brighter red circles indicate larger number of readings of a particular tag compared to a darker shade of tag.

B. Emulated RFID Based System

The distributed large scale testbed considers a large scale application scenario that requires significant communication and computational capabilities. This setup is used for the scalability study of the system. The testbed uses emulated MOs, emulated RFID tagged environment [2] and set of distributed VSs for scalability study.

The system is developed in C using MPI for communication among the system components. The system runs over a 53-node, 106-core Dell PowerEdge 1850 Linux cluster with dual Pentium4 Xeon EMT 64 processors using Infiniband interconnects and Gigabit Ethernet.

[2]We faithfully emulate the behavior of the Alien RFID reader for this large-scale set up. This allows scaling up the pervasive environment since the behavior of the real and emulated readers are indistinguishable. For more details on the emulated readers please refer to [13].

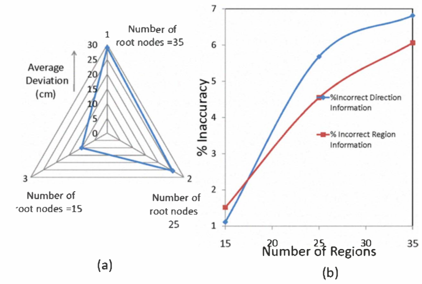

Figure 5. Measurements of a large indoor space. (a) Deviation from destination. (b) Percent inaccuracy in direction and region information.

We have considered a large scale indoor space for this experiment of 3900 sq foot which approximately corresponds to a 1100 x 1100 tag placement in a grid setup where the inter tag distance is 50 cm using emulated tags and readers. The results shown in Figure 9 confirm the soundness of our design in that the reading performance and accuracy is maintained in this larger deployment. The average deviation from a source to destination position is shown in Figure 5-(a). As can be seen from Figure 9-(a), the deviation from the desired destination is a function of the number of zones or regions defined by the root nodes. The deviation is 10 cm with 15 regions. It increases to 28 cm with 25 regions, and to 35 cm with 35 regions. The number of incorrect region information and direction information is shown for the same setup in Figure 5-(b). The level of inaccuracy increases with smaller zone area as we increase the number of root nodes. The region shows 1.51%, 4.54% and 6.06% incorrect region information and 1.1%, 5.68% and 6.18% incorrect direction information due to wrong zone information for a setup using 15, 25 and 35 regions, respectively. The level of accuracy is acceptable for the guidance information towards a room as the deviation from the destination is below 35cm.

Our results confirm the validity of a large scale emulation based indoor system for scalability purposes in terms of messaging among the different components. The provision for multiple VS in the system allows the VS to work in parallel in serving the MOs that would otherwise become a central bottleneck.

IV. Related Work

It is interesting to note that work related to ours falls across fairly diverse domains. First, there is research aimed at indoor positioning systems. The active badge system [1] uses IR sensing for providing location support which has line of sight problem. Radar [2] uses RF signal based location information and considers the signal strength information gathered at multiple locations to triangulate user location information. The Cricket [3] system uses ultrasound signals to find out precise location information. LotTrack [4] uses RFID and Ultrasound sensors for accurate location information. Landmarc [5] uses active RFID readers and reference

tags as an inexpensive solution for indoor location sensing. The positioning systems aim to provide precise location information. Our work is complementary as we proposed solution strategy considers the middleware level requirements to support guidance information to applications. The Sherlock system [14] uses an environment that has objects of interest using RFID tags along with two RFID readers mounted on a motor along with a camera to make localization decisions where the hardware cost is close to 10,000 dollars. Although the environmental consideration is similar to our work, we focus on a low cost environment using state of the art devices for use in daily lives. The Sixth Sense [15] system considers a tagged environment covered by readers which raises privacy concerns as the entire environment is being sensed constantly. Similarly the MAX system [16] considers a hierarchy of tagged environment that is observable by the base stations containing reader elements. A supportive environment for individuals requiring cognitive assistance is presented in Chang et. al. [17]. This system considers using a tag enaabled environment, similar to our approach, but focuses more on creating a unified interface that improves the user experience. Our work complements this approach, as we focus on the underlying system that would support such applications. The system described in Abascal et. al. [7] presents an environment for people with cognitive disability which provides context-aware information and intelligent decision making. Our work also expands on this approach, focusing specifically on RFID technology for monitoring and guidance purposes.Also worth noting are the programming abstractions described in Acharya et.al. [9], which provide for a high level virtualization architecture that enables a layer to aggregate queries. This is more generalized than our work, which focuses on a specific sensor technology. Other research has been done with RFID-based middleware systems. The work presented by Thiem et. al. [18] discusses a framework that combines RFID infrastructure with a wireless communication interface. This allows for the expansion of existing infrastructure, increasing environment coverage at a significantly lower cost than other options.

Systems like Savant [19], RFIDStack [20], High Fan-in Systems [21] and WinRFID [22] considers item tracking applications as opposed to guidance applications. RF^2ID [12] exploits the data flow for item tracking applications as opposed to guiding techniques. The concept of *path* is used in many different contexts including fault tolerance [23], profiling distributed systems [24], [25], and resource allocation [26], [27]. Scout OS [28] defines path abstraction to navigate through the layers of the network stack and Ninja project [29] utilizes path abstraction as a way to compose multiple services distributed on the Internet into a single logical unit. Our work is inspired by the use of paths in these various contexts.

V. Conclusions

We have presented a low-cost and effective middleware solution (GuardianAngel) based on passive RFID technology that can be used as a building block for indoor guidance and unobtrusive monitoring applications, such as in an assisted living environment. We proposed the basic system abstractions that would be necessary for such environments and showed an efficient implementation of these abstractions using passive RFID technology. By virtualizing the position information into zones, obfuscating precise timing information, and by giving user control on when and what to report for monitoring purposes, we make the system more user friendly for such environments. We showed through experimentation using real RFID devices in the small, and emulated readers in the large that GuardianAngel delivers close to 100% accuracy for zone information allowing the construction of very robust guidance and monitoring applications.

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